Sensor Node Failure or Malfunctioning Detection in Wireless Sensor Network

Ravindra N Duche[1],N.P.Sarwade[2]
[1]Department of Electrical Engineering, VJTI, Mumbai, India
Email:rnduche@rediffmail.com
[2]Department of Electrical Engineering, VJTI, Mumbai, India
Email: nishasarvade@vjti.org.in

***Abstract*— The rapid growth in electronics, sensors and communication technology has made it possible to construct the WSN consists of large number of portable sensors. Because of this measurement accuracy of various parameters in the field has been increased. It has increased the quality of WSN. But due to the use of large numbers of portable sensor nodes in WSN, probability of sensor node failure gets increased. It has affected the reliability and efficiency of WSN. To maintain the high quality of WSN, detection of failed or malfunctioning sensor node is essential. The failure of sensor node is either because of communication device failure or battery, environment and sensor device related problems. To check the failed sensor node manually in such environment is troublesome. This paper presents a new method to detect the sensor node failure or malfunctioning in such environment. The proposed method uses the round trip delay (RTD) time to estimate the confidence factor of RTD path. Based on the confidence factor the failed or malfunctioning sensor node is detected. Hardware based simulation result indicates the easy and optimized way of detecting failed or malfunctioning sensor node in symmetrical WSN.**

***Index Terms* — WSN, RTD, Portable Sensors, Confidence factor, Look-up table**.

I. Introduction

Wireless sensor network (WSN) consist of large number portable sensors (small, low-power and cost) placed in field measuring field with the help of wireless communication module. The advances in microelectronics and sensor technology made it possible to have such portable sensors [1, 3, 5]. The purpose is to sense, collect and process the information from all sensor nodes and then sending it to for analyzing [1-3].

The sensor node failure may occur in WSN due to uncontrolled environment, battery related problem, failure in communication device [1,2]. Failure detection is essential because failed or malfunctioning sensor node may produce incorrect analysis or detection of parameter [2,4]. Failed sensor node may decrease the quality of service (QOS) of the entire WSN [1]. Manually checking of such failed sensor node in WSN is troublesome. To achieve the good quality of WSN through accuracy, reliability and efficiency, detection of sensor node failure or malfunctioning is essential [1-3].

Ref. [1] detects the faulty node by using neighbor-data analysis method. In which node trust's degree is calculated. But the algorithm proposed is weak and not accurate. Ref. [2] uses time delay based direction of arrival (DOA) estimation and confidence factor to detect faulty sensor node. It suffers due non perfect planar wave fronts. Ref [5,7] measures the energy consumption of the node to detect the location. Networked predictive control

Over the Internet using RTD explained in [14] is highly efficient, hence used in this proposed method.

The objective of proposed method is to detect the sensor node failure or malfunctioning with the help of confidence factors. Confidence factor of round trip path in network is estimated by using the round trip delay (RTD) time [2,3].The proposed method will detect the failure in sensor node for symmetrical network conditions. In this way it helps to detect failed or malfunctioning sensor, which can be used to get correct data in WSN or the exact sensor node can be repaired or working status (health) of the WSN can be checked [1,3]. The time required for detection is in the range of sec; hence data loss can be avoided.

The remaining paper is organized into five sections. In Section II, round trip delay time concept is described. In Section III, proposed method and its realization is explained in detail. In Section IV, experimental work and related simulation results are presented. Result analysis is performed in section V. Conclusion and future work is stated in section VI.

II. Round Trip Delay Time

Round-trip delay (RTD) also called as round-trip time (RTT) [2, 3, 14] is the time required for a signal to travel from

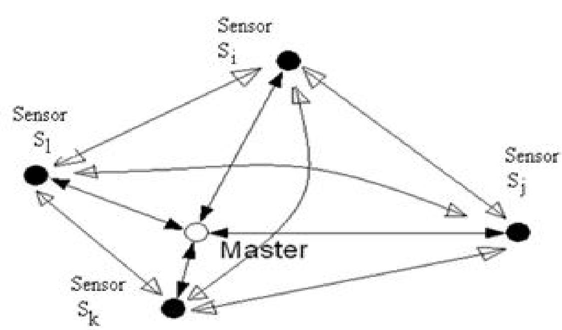

Figure 1. WSN with four slave sensor nodes and master node

a specific source node through a path consisting other nodes and back again. The round trip delay time for the path consisting three sensors i,j and k as shown in Fig.1, is[2] expressed as

$$\tau_{RTD} = \tau(i,j) + \tau(i,k) + \tau(k,i) \tag{1}$$

DOI: 01.IJCOM.3.1.3_1

where $\tau(i,j)$ is time delay between the sensor pair (i, j). RTD time is a function of various parameters of the wireless network [2,14] and it can be expressed as

$$RTD_{time} = \boldsymbol{f}\,(\text{speed, distance, medium, noise, nodes In RTD path \&request handled})$$

$$= Ts + Td + Tm + Tn + Tn_{RTD} + Toreq \qquad (2)$$

Thus round trip delay time is the summation of various time delays associated with the respective parameters of the WSN. This time can range from a few milliseconds to several seconds [1].

III. Proposed Method

In the proposed method sensor node failure or malfunctioning detection is achieved with the help of confidence factors of round trip paths in WSN [2,3]. The confidence factor of round trip path is computed with the help of threshold and instantaneous round trip delay time. Confidence factors of all round trip paths are stored in look-up table. Then by analyzing the status of confidence factor of all paths in the look-up table, failed or malfunctioning sensor node is detected easily.

In WSN if any sensor node fails or malfunctioning the time delays related to this sensor node will change. This will introduce errors in estimating the round trip delay (RTD) times [2,6]. To determine the confidence factor, measurement of threshold and instantaneous round trip delay time of respective path is essential. The round trip delay time of various round trip paths in WSN is measured for certain sensor conditions (related to type of sensor, microcontroller circuit and wireless modules used). The threshold value and confidence factor utilized here is a powerful tool for failure detection [2].

Two algorithms are proposed here to detect the sensor node failure or malfunctioning. First algorithm is to estimate the confidence factor of each round trip path in WSN and second is to analyze the look-up table to determine either sensor node is failed or malfunctioning.

Symmetrical Network Conditions: While implementing proposed method it is necessary to apply the following symmetrical network conditions [8]. The WSN will be symmetrical if

1) All the sensor nodes are located at equal distance from each other.
2) All sensor nodes have same sensitivity.
3) Operating speed of all sensor nodes is equal.
4) Same wireless communication module is for all sensor nodes
5) Location of all sensor nodes is fixed.

Otherwise it will be an asymmetrical network. In the proposed method it is essential to determine the maximum possible round trip paths in the selected WSN. This is because the size of look-up table depends upon this number. To optimize the sensor node failure detection time it is necessary to reduce the size of look-up table. It can be achieved by reducing the number of paths.

A. Estimation of maximum numbers of round trip paths.

Consider the symmetrical wireless network as shown in Fig. 1.The maximum possible round trip paths in this

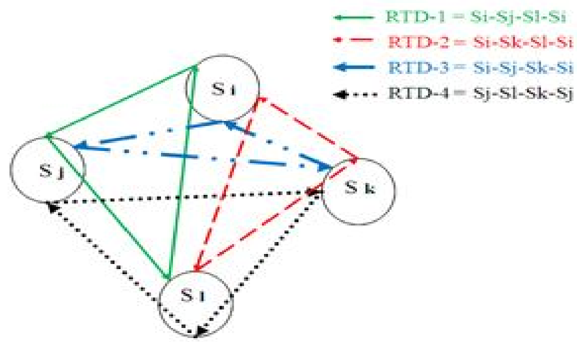

Figure 2. Four round trip paths in WSN

network is shown in the Fig.2.Round trip path in WSN will be formed with at least three sensor nodes including the source node. The number of sensor nodes in the path can be increased to maximum as N-1.The range of sensor nodes in round trip path can be [8] expressed as follows

$$3 \leq m \leq (N-1) \qquad (3)$$

here 'N' is the total number of sensor nodes present in WSN and 'm' is the number of sensor nodes present in the round trip path.

Let 'n_{RTD}' be the maximum number of round trip paths possible in WSN having N sensor nodes. It depends on intermediate sensor nodes (m) in round trip path [8]. If less or minimum (m=3) number of intermediate nodes are selected then round trip paths formed will be maximum. On the other hand if intermediate nodes are increased to maximum (m=N-1) then least number of round trip paths are formed. It is expressed by the equation

$$n_{RTD} = N\,(N- m) \qquad (4)$$

The four sensor nodes (i.e. N=4) are used here shown in Fig. 1.Let the minimum number of sensor nodes used in each path are 3 (i.e. m=3). The maximum possible number of round trip paths for round trip delay (RTD) measurement are found by using (3), and is n_{RTD}=4 paths. Hence this WSN have maximum four round trip paths. These four paths are shown in Fig. 2. As the symmetrical WSN is considered here the round trip delay time for all four paths will be equal as,

$$\tau_{RTD-1} = \tau_{RTD-2} = \tau_{RTD-3} = \tau_{RTD-4} \qquad (5)$$

Where RTD-1, RTD-2, RTD-3and RTD-4 are the four round trip paths.

B. Threshold round trip delay (RTD) time of path

As round trip delay time is affected by several factors of WSN, it is necessary to determine the proper maximum time. Also to place the sensor node at equidistance is not possible in large network [7,14]. Because of it the delay time associated with each sensor node and it will change the round trip delay time too [2,3]. The maximum value of this time will be the threshold value of the corresponding path. The threshold time for respective round trip path is calculated as

DOI: 01.IJCOM.3.1. 3_1

$$\tau_{RTD-Tr} = \left(\hat{\tau}(i,j) + \hat{\tau}(j,k) + \hat{\tau}(k,i) \right) \quad (6)$$

where $\hat{\tau}(i,j)$ is the maximum time delay[2,6] between the two selected sensor nodes i and j. To measure threshold value of any round trip path in WSN, choose the round trip path and then by using (1), measure the RTD time. Repeat the measurement of time till we will get the constant maximum value of RTD time.

Continue above procedure for remaining round trip paths in the WSN. Threshold values of all round trip paths in WSN are now stored in look-up table.

C. Confidence Factor Estimation

Confidence factor is estimated by comparing the instantaneous and threshold round trip delay time. The instantaneous value of round trip delay (RTD) time is measured by using (1).Estimation of confidence factor is expressed as [2-4].

$$\Delta_{RTD} = \begin{cases} 1 \;, & \tau_{RTD} < \tau_{RTD-Tr} \\ 0 \;, & \text{otherwise} \end{cases} \quad (7)$$

where τ_{RTD-Tr} is the threshold value of round trip delay adjusted for the maximum value of time and Δ_{RTD} is a confidence factor for the selected round trip path in WSN. Confidence factor will be either 0 or 1. If a sensor node fails, all of its time delays will be corrupted. In addition, it may also happen (due to noise) that time delays from one of the properly operating sensors will get corrupt. In these cases the instantaneous time will be more than threshold. The respective round trip path has '0' confidence factor in which this sensor is present.

If sensor nodes in the round trip path are working properly then its instantaneous time will be less than threshold time. Hence confidence factor of such round trip path will be '1'.The algorithm to determine the confidence factors of various round trip paths in wireless sensor network is explained as follows:

Algorithm: 1] Estimation of Confidence factors

1. Initialize all Sensor nodes in the Network.
2. Select 3 sensor nodes for round trip path (m=3).
3. Determine the number of round paths in WSN (i.e. here $n_{RTD} = 4$)
4. Set the counter for round trip paths.
5. Select the round trip path (e.g. Si-Sj-Sk-Si).
6. Know calculate the instantaneous round trip delay (RTD) time of this path by using the equation

$$\tau_{RTD} = \tau(i,j) + \tau(i,k) + \tau(k,i)$$

7. Estimate confidence factor of respective round trip path by using following condition

$$\Delta_{RTD} = \begin{cases} 1 \;, & \tau_{RTD} < \tau_{RTD-Tr} \\ 0 \;, & \text{otherwise} \end{cases}$$

8. Go to step 4, decrement the counter for RTD path and repeat till step 7 to determine the confidence factor of all paths in the WSN.
9. Complete the look-up table entries for all RTD paths.
10. Stop.

D. Analysis of Look-Up Table

Look-up table contains instantaneous and threshold RTD time as well as the confidence factors of all round trip paths of WSN. Analysis of look-up table can be done for two cases. First case is for sensor node failure. In this case time delay associated with faulty senor node becomes infinity [2, 3]. Because of this RTD time of path in which this sensor node is present will also become infinity. If instantaneous time is observed as infinity in look-up table then sensor node failure is confirmed. In second case if instantaneous time is not infinity, which means sensor node in WSN is malfunctioning.

The second algorithm proposed for the analysis of look-up table is presented in the form of flowchart shown in Fig.3. The different cases of sensor node failure are considered and related results are presented in Table I. In first IV cases, any one sensor node is assumed to be failed. Hence the confidence factors of round trip paths in which this sensor is present will be '0', and is listed in Table I.

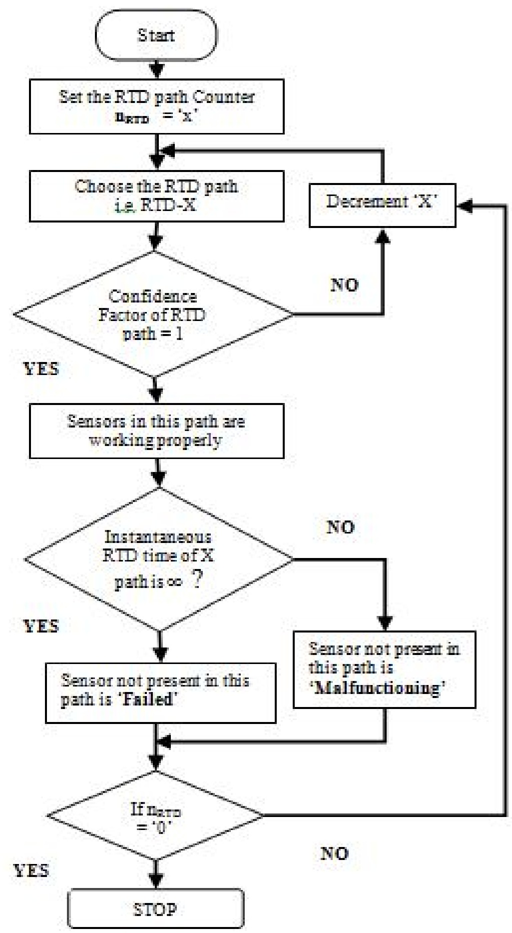

Figure 3. Flowchart For the Analysis of Loo-Up Table

In case V, all sensor nodes in network are assumed to be functioning properly then confidence factors of all paths will be '1' only. This concludes that all sensor nodes in case V are working properly.

DOI: 01.IJCOM.3.1.3_1

TABLE I. DIFFERENT CASES OF SENSOR NODE FAILURE

Round Trip Paths in WSN	Confidence Factor (Δ_{RTD}) Values				
	Case I	Case II	Case III	Case IV	Case V
Si-Sj-Sl-Si (RTD-1)	0	1	0	0	1
Si-Sk-Sl-Si (RTD-2)	0	0	0	1	1
Si-Sj-Sk-Si (RTD-3)	1	0	0	0	1
Sj-Sk-Sl-Sj (RTD-4)	0	0	1	0	1
Faulty Sensor Node	S_l	S_k	S_i	S_j	NIL

IV. EXPERIMENTAL DETAILS

A. Hardware Implementation

Recently a new wireless communication standard based on IEEE 802.15.4 radio interface–ZigBee[9-13] designed for automation purposes have emerged. The electronics for ZigBee devices is much simpler than electronics of Bluetooth devices [13]. The existence of automation device profiles and low power consumption (compared to Bluetooth) makes the ZigBee an ideal wireless interface for automation devices [3].

Typical experimental setup consisting four microcontroller based sensor nodes with ZigBee wireless module is as shown in Fig.4.Each Sensor node in WSN for the experimental purpose to verify the proposed method is designed using ATMEGA 16 L low- power, high-performance CMOS 8-bit micro-controller and ZigBee (XBEE S2 by Digi Key) wireless device.

B. Real Time Simulation Result

Initially the RTD paths are defined by configuring the sensor node using the X-CTU software. In this configuration source and destination paths for each sensor is assigned for the particular path. The three sensor nodes are kept at equal distance of 1 foot [5,13]. After configuring the sensor nodes, whole network is simulated in real time by using the Dock light V1.9 software. The network is simulated repeatedly for 50 times to obtain the threshold round trip delay time.

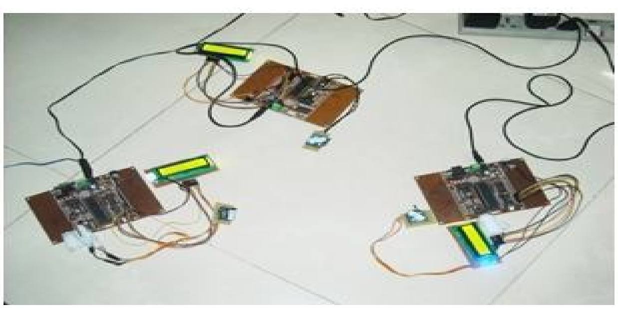

Figure 4. Experimental setup for symmetrical WSN

Different round trip delay times measured are 14.623, 14.623, 14.623, 14.624 and 14.623 sec [3,14].Finally the threshold time for RTD-1 path is selected as **14.624 sec** (maximum value of RTD time). Due to symmetrical network the threshold values for all paths in WSN are same. Practical RTD time equals to 14.624 sec.

While performing this experiment the baud rate of ZigBee is set to 9600 bps and 11.0592 MHz crystal is used for ATMEGA 16L.The transmission time required by ZigBee is near about 4.6 sec and processing time taken by microcontroller is in the range of 0.3 to 0.4 s. The time delay between the sensor node pair will be approximately 4.8 sec. Hence theoretical round trip delay time will be **14.40 sec** [14].

The theoretically calculated and practical round trip delay times are not same. Hence it is necessary to measure the threshold value of RTD time. Threshold values of all round trip paths shown in Fig.4 are measured. Next experiment is performed to detect failure of sensor node in two cases as follows.

C. Detection of failed sensor node

The wireless network shown in Fig.4 is simulated in real time for this case. The simulation results of instantaneous RTD time of two paths with their respective confidence factor are presented in Table II.

Here sensor node Sj is made faulty by switching it off. Due to it time delays associated with it will become infinity and round trip couldn’t be completed. This will set RTD time as infinity of the path in which Sj is node is present. Confidence factor of round trip path 2 is ‘1’ and ‘0’ for remaining three paths in the selected WSN. Sensor nodes belonging to round trip path RTD-2 are not faulty (i.e nodes Si, Sk and Sl are not faulty). In remaining three round trip paths it is found that Sj sensor node is present. At the same time the instantaneous RTD time for these paths is infinity. These two results conclude failure of sensor node Sj. Same procedure is repeated for senor node Sl.

D. Detection of malfunctioning behavior of sensor node.

One sensor node of the network shown in Fig.4, is made slow to check the malfunctioning behavior. This is done by adding a delay of 5 sec to the corresponding sensor node. As all sensor nodes are kept at distance of 1 foot, here the threshold time is 14.624 sec.

TABLE II. RESULTS IN CASE OF SENSOR NODE FAILURE

Round Trip Paths in WSN	Instantaneous RTD time (sec)	Confidence Factor	Instantaneous RTD time (sec)	Confidence Factor
Si-Sj-Sl-Si (RTD-1)	∞	0	∞	0
Si-Sk-Sl-Si (RTD-2)	14.623	1	∞	0
Si-Sj-Sk-Si (RTD-3)	∞	0	14.624	1
Sj-Sl-Sk-Sj (RTD-4)	∞	0	∞	0
Failed Sensor Node		Sj		Sl

For experimental purpose delay is added alternately to Sj and S_l nodes respectively. Then WSN is simulated to find the instantaneous RTD times for two cases. The results of simulation of all round trip paths for two cases are listed in Table III. As the confidence factor of round trip path RTD-2

DOI: 01.IJCOM.3.1. 3_1

TABLE III. RESULTS OF SENSOR NODE MALFUNCTIONING CASE

Round Trip Paths in WSN	Instantaneous RTD time (sec)	Confidence Factor	Instantaneous RTD time (sec)	Confidence Factor
Si-Sj-Sl-Si (RTD-1)	20.120	0	19.792	0
Si-Sk-Sl-Si (RTD-2)	14.623	1	20.063	0
Si-Sj-Sk-Si (RTD-3)	19.870	0	14.624	1
Sj-Sl-Sk-Sj (RTD-4)	19.892	0	19.980	0
Malfunctioning Sensor Node		Sj		Sl

is '1', the sensor nodes belonging to this path are not malfunctioning. Hence the sensor Sj which is not a part of this round trip path is marked as faulty. For the second case confidence factor of round trip path RTD-3 is '1, hence the sensor node S_l is faulty here. Along with this the instantaneous RTD times for above two cases are not infinity. Therefore sensor node Sj and S_l are concluded as malfunctioning sensors.

V. Result Analysis

The detection time of proposed method to detect faulty sensor node is in the range of few sec. To minimize the detection time of this proposed method, number of round trip paths in wireless network has to be optimized. But there exists tradeoff between number of sensor nodes in round trip path and maximum possible RTD paths.

It is difficult to judge the failure or malfunctioning of sensor node more than one if they belong to same round trip path. This is due to the reason that instantaneous RTD time for all paths will be either infinity or more than threshold value. Which will tend to set the confidence factors of all round trip paths in WSN equal to '0'.Because of it look-up table analysis will be failed. If the faulty sensor nodes belong to different round trip paths in network then they will be detected by this method. This is because the confidence factors of all round trip paths in WSN will not tend to be '0'.

VI. Conclusion And Future Work

The proposed method requires few computations in case of symmetrical network conditions. Because of this it requires less time and has good accuracy. By using this method we can detect one faulty node present in any path in an easy and efficient way. Fault in terms of failure or malfunctioning is detected correctly by the proposed second algorithm.

The wireless device interfaced with sensor circuit plays a major role in the measurement of round trip delay time. So selection of efficient wireless communication module is essential. For such detection scheme Bluetooth as well as ZigBee are best suited modules.

Proposed method has to be modified to optimize the number of round trip paths in WSN and the number of sensor nodes in the corresponding paths. This will reduce the detection time of faulty sensor node in WSN.

Reference

[1] Peng Jiang, "A New Method for Node Fault Detection in Wireless Sensor Networks" Sensors, pp. 1282-1294, 2009.

[2] T. W. Pirinen, J.Yli-Hietanen, P. Pertil and A. Visa, "Detection and compensation of Sensor malfunction in time delay based direction of arrival estimation " IEEE Circuits and Systems,vol.4,pp.872-875,May 2004.

[3] A. De Angelis, A. Moschitta, Peter Händel and Paolo Carbone, "Experimental Radio Indoor Positioning Systems Based on Round-Trip Time Measurement" Advances in Measurement Systems, pp.196-219,April 2010.

[4] K. Varma, T. Ikuma, and A. A. Beex, "Robust TDE-based DOA-estimation for compact audio arrays," in Proceedings of the Second IEEE Sensor Array and Multichannel Signal Processing Workshop,pp.214–218, 2002.

[5] A.A.Boudhir,B.Mohamed and Ben A.Mohamed, "New Technique of Wireless Sensor Networks Localization based on Energy Consumption" International Journal of Computer Applications, Vol. 9–No.12,pp.25-28,Nov 2010.

[6] T. Pirinen, P. Pertil, and A. Visa, "Toward intelligent sensors - reliability for time delay based direction of arrival estimates," in Proceedings of the 2003 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP'03), Volume V, pp.197-200, 2003.

[7] Chuan-Chin Pu, Chuan-Hsian Pu, and Hoon-Jae Lee, "Indoor Location Tracking using Received Signal Strength Indicator" Emerging Communications for Wireless Sensor Networks,pp.229-256,2010.

[8] R.N. Duche, N.P. Sarwade, "Round Trip Delay Time as a Linear Function of Distance between the Sensor Nodes in Wireless Sensor Network" International Journal of Engineering Sciences & Emerging Technology, Volume 1, Issue 2, pp: 20-26, Feb 2012.

[9] Corral P, Pena E, Garcia R, Almenar V, C. Lima, "Distance Estimation System based on ZigBee" Proceedings of 11th IEEE International Conference on Computational Science and Engineering Workshops, CSEWORKSHOPS '08, San Paulo,pp.405–411,July 2008.

[10] Cho H, Kang M, Park J, Park B. & Kim H, "Performance Analysis of Location Estimation Algorithm in ZigBee Networks using Received Signal Strength" Proceeding of 21st IEEE International Conference on Advanced Information Networking and Applications Workshops,AINAW'07,NiagaraFalls, CA,2007.

[11] Santinelli G, Giglietti R. & Moschitta A, "Self-calibrating indoor positioning system based on ZigBee Devices" Proceedings of the IEEE Inter. Instrum. & Measurement Techn. Conference (I2MTC),pp.1205– 1210,May 2009.

[12] Schwarzer S, Vossiek M, Pichler M & Stelzer A, "Precise distance measurement with IEEE 802.15.4 (ZigBee) devices" IEEE Radio and Wireless Symposium, Orlando, FL, pp. 779 – 782, Jan 2008.

[13] Harish R,B S Prabhu, Rajit Gadh, Asad M. Madni, "Wireless Industrial Monitoring and Control using a Smart Sensor Platform" accepted for IEEE Sensor Journal 2007.

[14] Wenshan Hu, G.Liu and D. Rees, "Networked Predictive Control over the Internet Using Round-Trip Delay Measurement" IEEE Transactions On Instrumentation And Measurement, Vol.57, 10, pp. 2231-2240, October 2008.

DOI: 01.IJCOM.3.1. 3_1